APPENDIX G

DILUTION OF RESIDUALLY RADIOACTIVE SCRAP STEEL

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DILUTION OF RESIDUALLY RADIOACTIVE SCRAP STEEL

This appendix describes the development of the dilution factors discussed in Section 5.4.1 and used to assess the radiation exposures of individuals that result from recycling potentially contaminated steel scrap.

G.1 INTRODUCTION

Chapter 5 discusses the operations and scenarios used to assess the radiation exposures of the RME individual resulting from the recycling of potentially contaminated steel scrap. Each operation exposes the individual to materials or products generated during a certain stage of the recycling process. It is unlikely that for an entire year,[1] any steel mill would be exclusively supplied with scrap resulting from the dismantling of potentially contaminated components. To determine the largest fraction of steel scrap that would be potentially contaminated, the anticipated release of scrap steel by various generator sites nationwide was matched to the scrap processing capacities of nearby steel mills. This appendix presents a discussion of that analysis.

"Electric Arc Furnace Roundup" (1996) listed 213 furnaces with a combined nominal capacity of 57,850,000 tons per year.[2] The largest furnace in this survey was a 370-ton furnace with a nominal capacity of 950,000 tons per year; the smallest was a 10-ton furnace with an annual capacity of 4,000 tons. The average annual capacity of all the furnaces in the survey was 272,000 tons. EAF steel production in 1995 was 40,619,000 tons (AISI 1995), which suggests that the industry was running at about 70% of capacity during that year.

One important factor in developing worker exposure scenarios is the number of furnaces at a site. If there are multiple furnaces at a site, the worker exposure may be related to the total steel tonnage produced at the site rather than the tonnage produced by a single furnace. Recognizing the importance of these and other factors, one can make some estimates as to how operating conditions may alter worker exposure from melting residually radioactive steel scrap. First, an average exposure case will be considered, followed by a reasonable maximum exposure case. In

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[1] The potential radiological impacts on the RME individual are assessed for the year of peak exposure.

[2] Statistical data on U.S. steel production and the steel inventories of nuclear power plants are normally presented in English units (1 ton = 907.2 kg). To present the data as published and to avoid tedious repetition, these values are not generally converted to metric units in this appendix.

addition to determining the dilution factors for the steel mill scenario, the discussion will also cover the dilution of potentially contaminated scrap in the truck carrying steel to the scrap processor, the maximum likely dilution factor for any one furnace charge, and the dilution factor of contaminated EAF dust at a high temperature pyrometallurgical metals recovery plant.

G.2 AVERAGE CASE

According to Table A-81, the total inventory of carbon steel in U.S. commercial nuclear power plants—the 104 currently licensed reactors and the 17 reactors which are permanently shut down and in SAFSTOR or scheduled for DECON—is estimated to be about 3.5 million metric tons (t). As shown in Table A-84, the release of scrap metal from these facilities is expected to begin in 2006, with the bulk of the metal being released during a 40-year period starting in 2019. An average of 89,000 t of carbon steel scrap would be generated each year during this period. If all of this steel were shipped as scrap to a single "average" EAF, it would represent about 35% of the annual capacity *of that furnace alone*. If it were evenly distributed among all the furnaces in the United States, this scrap would represent 0.16% of total EAF capacity.

G.3 REASONABLE MAXIMUM EXPOSURE CASE

The NRC has divided the 48 contiguous states into four administrative regions, which are depicted in Figures G-1 to G-4. Superimposed on these maps are the locations of steel mills employing EAFs, as well as the locations of nuclear power plants and major DOE facilities that constitute present and future sources of potentially contaminated scrap metal. These maps show that both EAFs and nuclear facilities are broadly distributed across the country. A cursory examination reveals that, with two exceptions, each state that is host to a nuclear facility also has one or more EAF shops or is adjacent to a state that has such shops[3]. Since transportation costs would be a major factor in determining which EAF shop receives the scrap from a given nuclear facility, the geographical distribution of nuclear facilities and scrap melters should lead to the scrap being distributed among many EAFs. However, the simultaneous shutdown of two or more nuclear power plants in the same vicinity could lead to the release of a relative large amount of scrap at a single location for a brief period of time. A few hypothetical examples of such releases, and their consequences, are discussed in this section.

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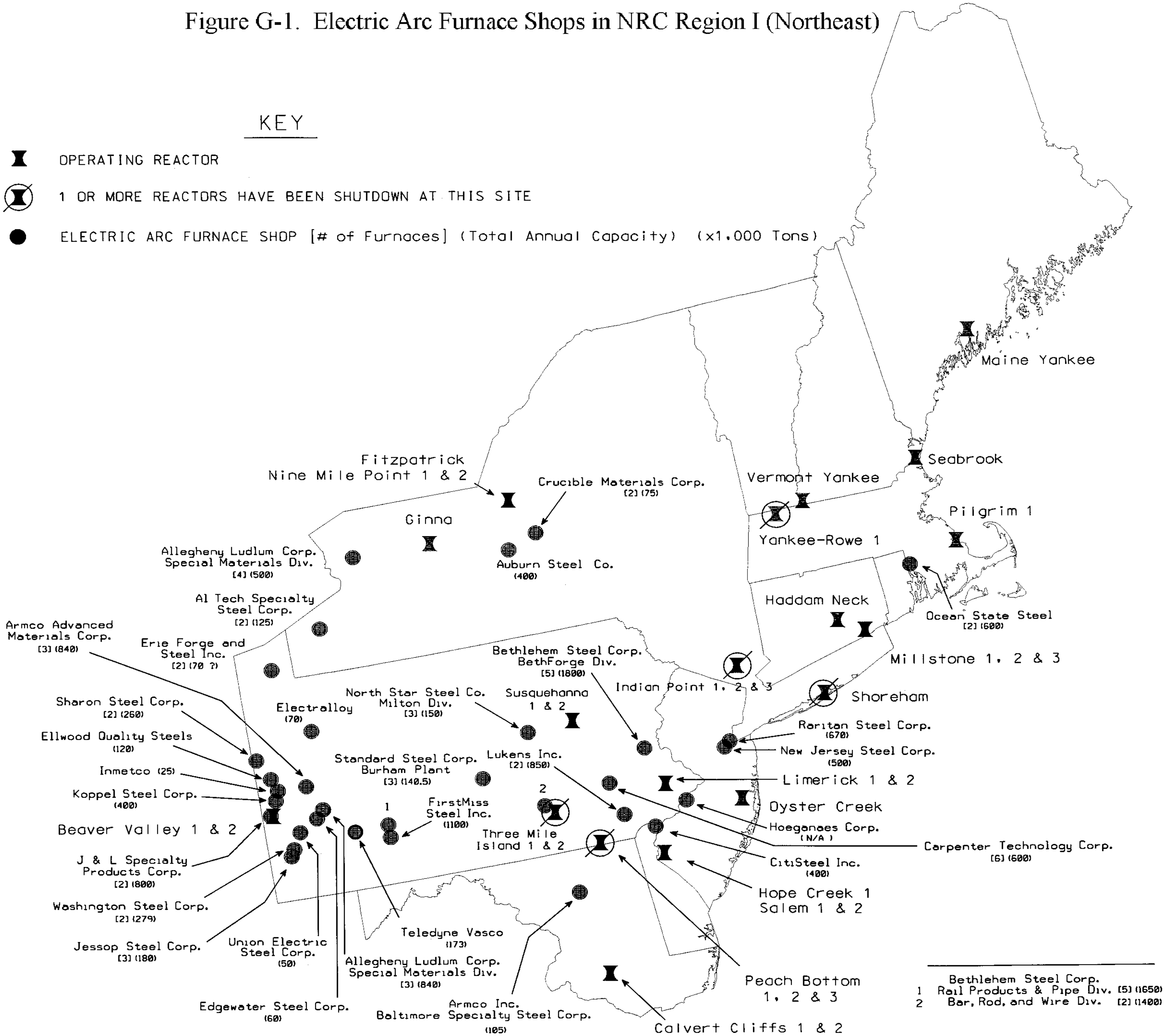
[3] The exceptions are Maine and New Hampshire. The nuclear plants in these states are nevertheless closer to the nearest EAFs than are some of the nuclear facilities in the West. The scales of the maps, which are different for the Northeast and Western regions, may give a different visual impression.

To develop the reasonable maximum exposure case, it was assumed that scrap steel tends to move the shortest possible distance to minimize transportation costs. For example, when the five nuclear power plants in southern California (San Onofre 1, 2, and 3, and Diablo Canyon 1 and 2) are dismantled, it was assumed that the carbon steel scrap would be shipped to TAMCO, near Riverside, Calif., for melting. Based on the time table developed in Section A.5.4, scrap from these five plants would be released between 2031 and 2052. Two of these reactors, San Onofre 2 and 3, are scheduled to shut down in 2022. Although decommissioning of a nuclear power plant can take several years (Smith et al. 1978), for the purpose of a conservative analysis, it was assumed that all the recyclable scrap metal would be released in a single year. According to Table A-29, the decomissioning of the Reference 1,000 MWe (1 GWe) PWR would generate up to 33,000 t of carbon steel scrap. Applying the scaling factors that reflect the power ratings of these reactors (see Section A.5.2.1) and converting to English units, it was found that up to 76,000 tons would be available in 2032 from these two units. This is about 19% of the 400,000-ton nominal annual capacity of TAMCO *for that year alone*. By the same logic, the other three units, each scheduled to be shut down in a different year, would use less than 10% of TAMCO's capacity in any one year.

Not all the carbon steel scrap generated by the decommissioning of a commercial nuclear power plant would consist of the potentially contaminated, recyclable metal that is the subject of this analysis. Some of the scrap generated during decommissioning would never have been exposed to radioactive contamination (and would therefore be outside the scope of the analysis), while other metal would have neutron activation products throughout its volume or would be so heavily contaminated that it would not be a candidate for clearance. Table A-80 indicates that a maximum of 3,311 t of carbon steel from the Reference PWR and 6,754 t of carbon steel from the Reference 1 GWe BWR would be residually radioactive metal potentially suitable for clearance. Again applying the appropriate scaling factors and converting to English units, it was found that only about 7,700 t of potentially contaminated scrap from San Onofre 2 and 3 would be available for clearance. Such scrap would constitute about 1.9% of TAMCO's nominal annual capacity.

In this hypothetical scenario, any stainless steel available for recycle would have to be shipped elsewhere, since TAMCO is a carbon steel shop.

Figure G-1. Electric Arc Furnace Shops in NRC Region I (Northeast)



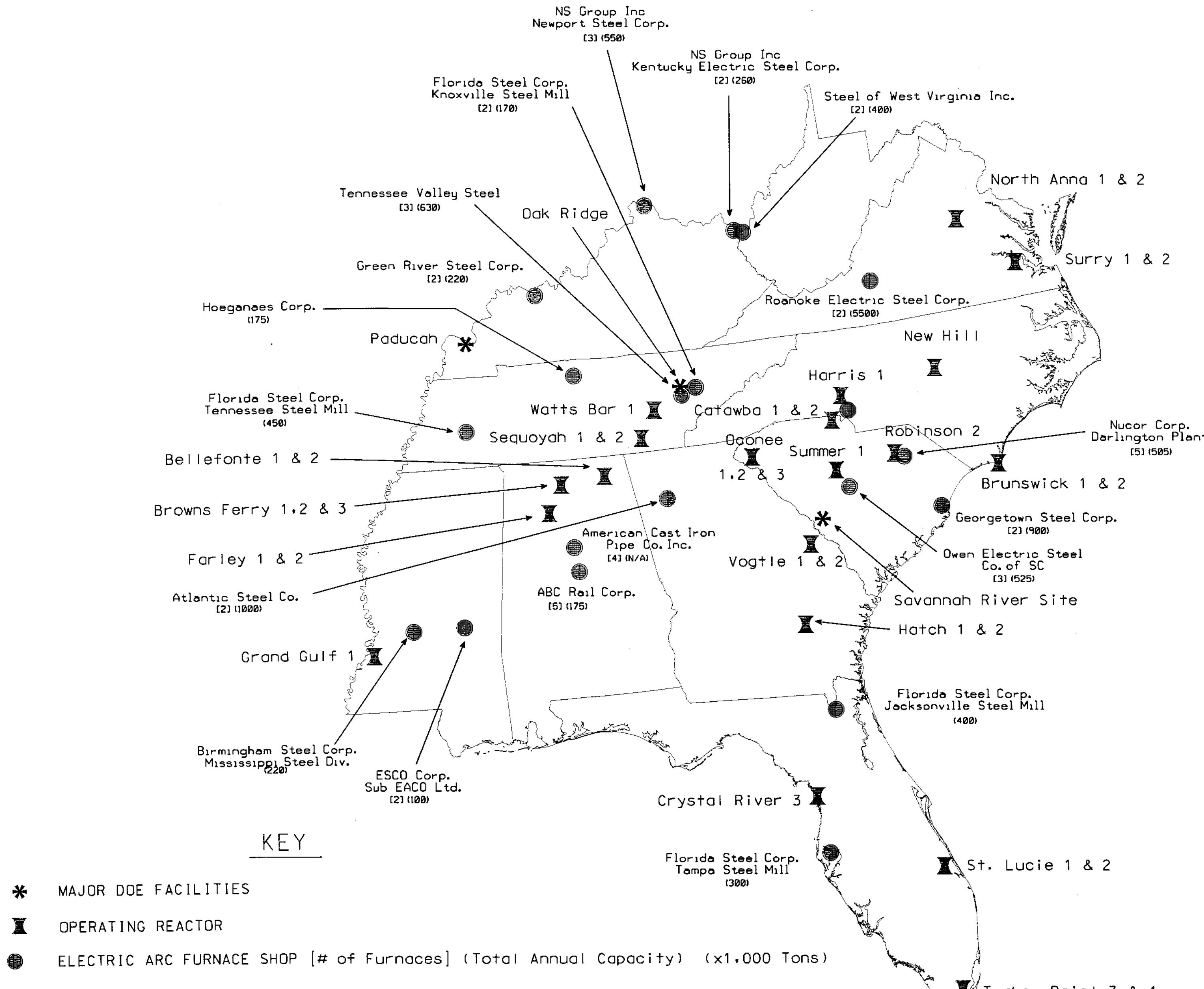


Figure G-2. Electric Arc Furnace Shops and Nuclear Facilities in NRC Region II (Southeast)

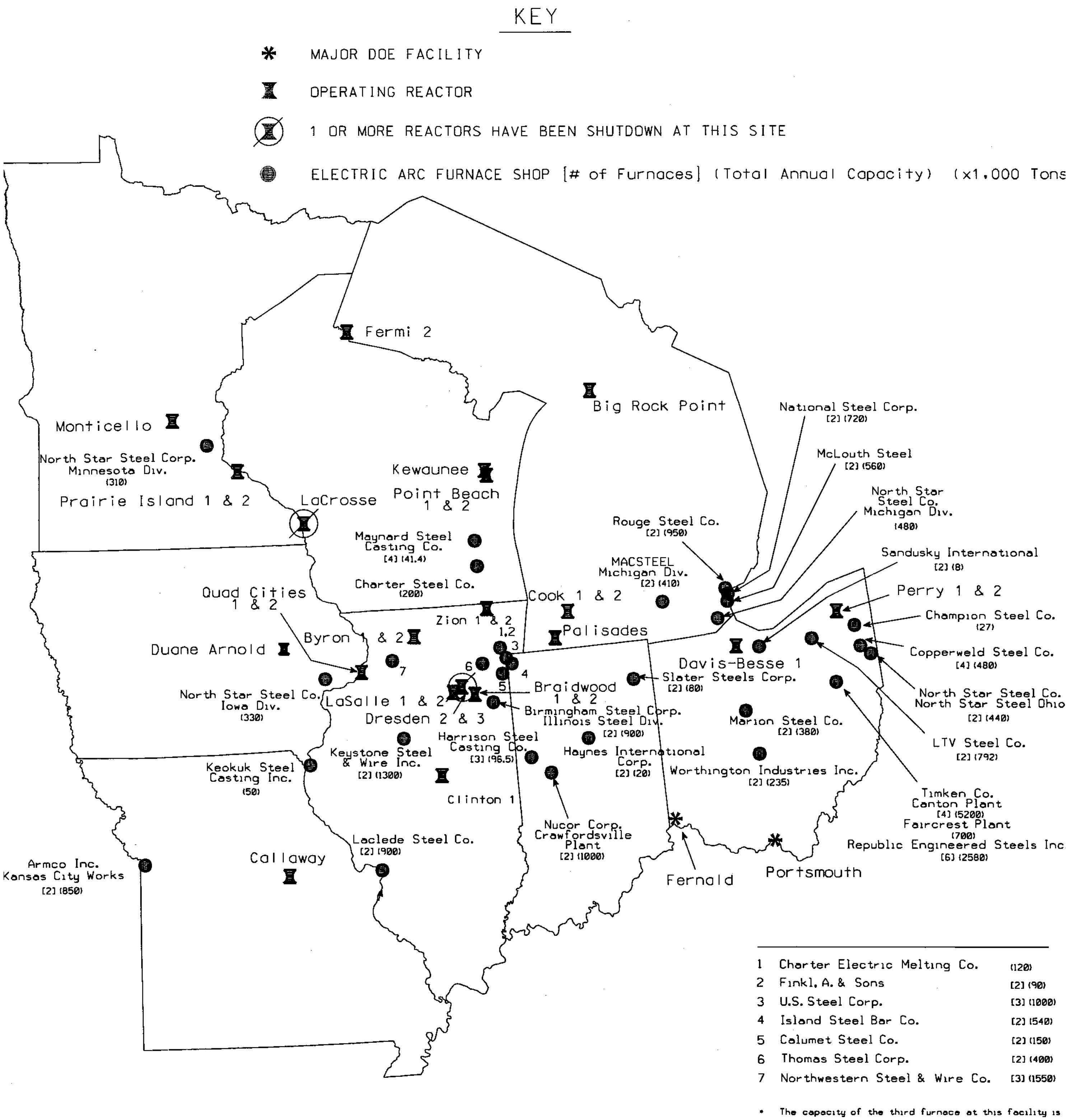


Figure G-3. Electric Arc Furnace Shops and Nuclear Facilities in NRC Region III (North Central)

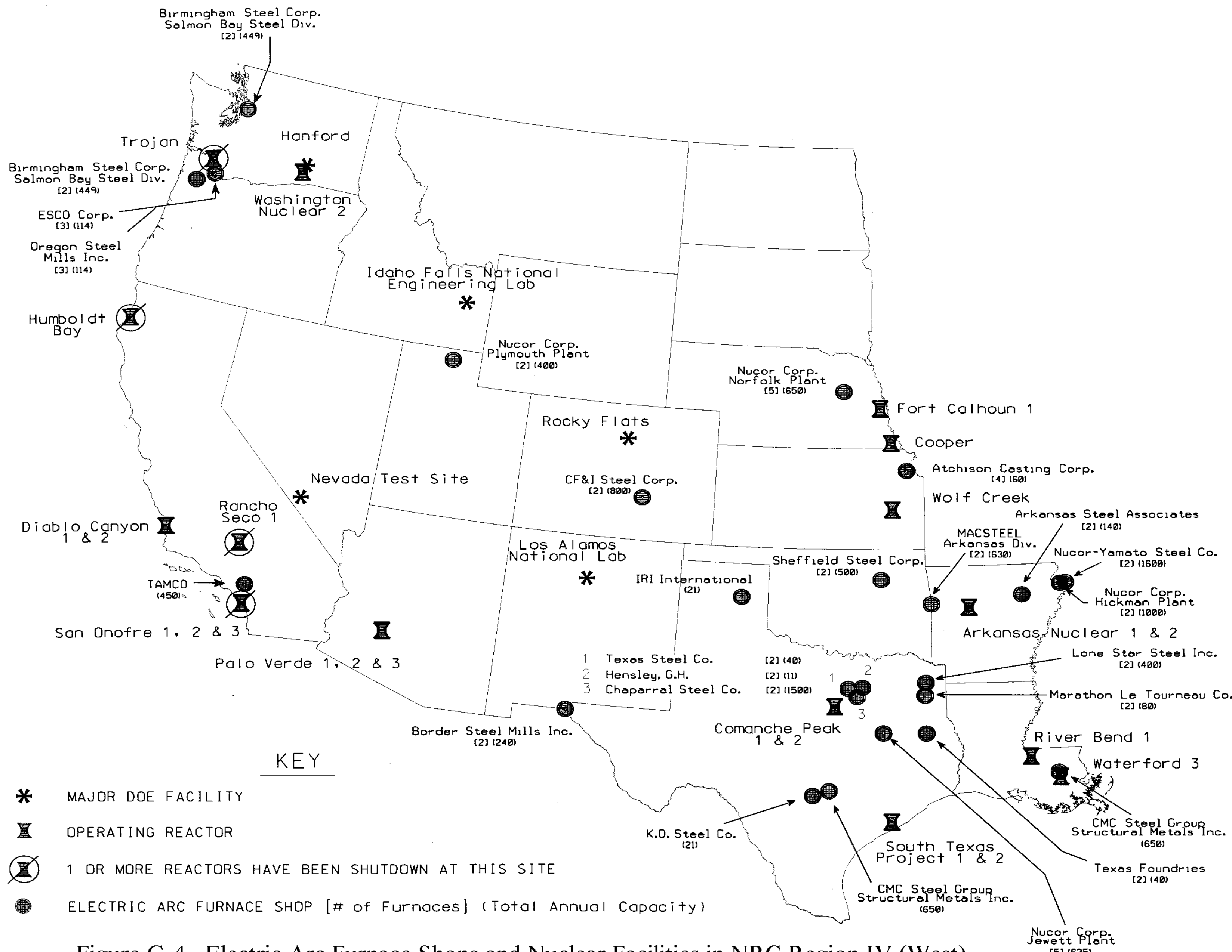


Figure G-4. Electric Arc Furnace Shops and Nuclear Facilities in NRC Region IV (West)

The three peak years for reactor shutdowns are expected to be 2013, 2014, and 2026. Nine reactor operating licenses are due to expire that first year[4]. Again assuming a ten-year delay between shutdown and release of scrap metal, up to 260,000 tons of carbon steel would be released in 2023. Two of these plants—Kewaunee and Point Beach 2—although belonging to different utilities, are near one another. The total amount of carbon steel scrap from these plants—about 46,000 tons—is still less than the amount from San Onofre 2 and 3. Of the remaining seven plants, each is located in a different state. Eleven plants are anticipated to shut down in 2014, resulting in the release of up to 350,000 tons of carbon steel in 2024. Only two of these facilities—Three Mile Island 1 and Peach Bottom 3—are located in the same state. These plants are owned by different utilities; although they are only about 40 miles apart, the profusion of EAF shops in the area makes it unlikely that all the carbon steel scrap from both plants would be recycled in the same facility during the same year. The remaining nine nuclear plants are each located in a different state. Nine plants are anticipated to shut down in 2026, resulting in the release of up to 350,000 tons of carbon steel in 2036. Two of these plants, Braidwood 1 and Byron 2, are both owned by Commonwealth Edison and are less that 100 miles apart. Up to 77,000 of scrap is projected to be released from these plants in 2036, about the same as the amount from San Onofre 2 and 3. Thus, little or no new geographical concentration is projected in any of these three years.

G.4 ADOPTED APPROACH TO DILUTION

G.4.1 Scrap Transport Scenarios

Once the scrap metal is cleared, there would be little reason to segregate residually contaminated metal from scrap that has never been exposed to radioactive contamination. Given this assumption, the highest fraction of contaminated scrap would be generated during the decomissioning of a BWR—as stated above, out a total of 34,000 t of carbon steel in a 1.0 GWe BWR Reference reactor facility, 6,753 t, or about 20%, would be residually radioactive metal that could potentially be cleared.

G.4.2 Recycle Scenarios

The largest total amount of carbon steel scrap—as well as the largest amount of residually radioactive scrap that could potentially be cleared—from any single commercial facility is

[4] See Table A1-1 in Appendix A-1.

anticipated to be from the decommissioning of Perry 1 in northeastern Ohio in 2036. The total amount of carbon steel scrap in this 1,160-MWe reactor is calculated to be 37,540 t, of which 7,455 t would be potentially contaminated. As shown in Figures G-1 and G-3, there are a number of EAF facilities in western Pennsylvania and northeastern Ohio which are relatively near to this reactor site. The annual capacity of the EAF shops in northeastern Ohio alone varies from a few thousand tons to over one million tons. Since it is difficult to predict which of these shops are likely to receive this scrap, it was assumed that the scrap would be recycled at the reference facility described in Chapter 5. Since this 150,000-ton-per-year EAF shop, with two furnaces, has a smaller annual production than the 272,000-ton-per-furnace national average, such an assumption is reasonably conservative.

Factors which could further reduce the quantity of scrap from nuclear facilities melted in a given shop include:

- incompatibility of scrap with product specifications
- incompatibility of large, single-source commitments with other purchasing arrangements
- reluctance to handle such scrap irrespective of actual risks
- scrap buy-back arrangements with customers
- release of scrap from the decommissioning of a reactor over a period of several years

One factor which could possibly increase the use of such scrap by a given recycling facility is the possibility that its price would have to be heavily discounted in comparison to comparable non-nuclear scrap, and that some marginal melt shops might seize the opportunity to purchase cheap scrap for a quick profit.

G.4.3 Finished Product Scenarios

If each EAF charge consisted of scrap from a single source, it would be quite likely—indeed, inevitable—that some of the 2,000 heats produced during the one year that the reference facility is processing decomissioning scrap would be composed entirely of residually contaminated steel. In reality, that is never the case. According to Tom Danjczek (1999), President of the Steel Manufacturer's Association and a former EAF supervisor, a single charge would contain steel from 5 to 20 sources. Using the geometric mean of this range—10 sources per furnace charge—a computerized Monte-Carlo simulation was performed to determine the maximum likely fraction of contaminated scrap in any single charge. In this simulation, the first 7.5 tons of the first 75-ton charge was randomly selected from the annual supply of 150,000 tons of scrap, comprising 7,500 tons of contaminated scrap and 142,500 tons of clean scrap. Whichever source was utilized was decreased by 7.5 tons and the process was repeated until the 75-ton furnace was fully charged. The next charge was then made up in the same manner, utilizing the now-decreased scrap supply; the process was continued until the entire supply was exhausted. The simulation was repeated 1,000 times. The highest fraction of contaminated scrap in *any* heat in 1,000 simulations of 2,000 heats each was 0.6. The 90th percentile fraction of contaminated scrap was equal to 0.5—this was the highest fraction in any of the 2,000 heats that was exceeded in fewer than 10% (100 out of 1,000) of the simulations. (In fact, the 95th percentile fraction was also 0.5.) Consistent with EPA's definition of reasonable maximum exposure, the 90th percentile value—a dilution factor of 0.5—was adopted for the exposure assessment of the finished product scenarios.

G.4.4 Processing of Baghouse Dust

Most of the EAF dust generated in the United States between 1992 and 1995 was shipped to high temperature pyrometallurgical metals recovery plants owned and operated by the Horsehead Resource Development Company (HRDC). HRDC operates three regional Wealz kiln plants, located in Palmerton, Penn.; Chicago; and Rockwood, Tenn., that have a cumulative annual capacity of about 450,000 tons per year (Bossley 1994, Schmitt 1996). Based on information in U.S. EPA 1994, HRDC was assumed to have a total of six Wealz kilns, three of which are in Palmerton, two in Chicago and the remaining one in Rockwood. Apportioning the processing capacity equally among the six kilns, the annual capacity of the Palmerton facility was assumed to be 225,000 tons; Chicago: 150,000 tons; and Rockwood: 75,000 tons.

All baghouse dust generated by the melt-refining of carbon steel scrap released during the decomissioning of a nuclear power plant was assumed to be processed at the HRDC facility nearest to that plant. The maximum amount of potentially contaminated scrap released during any one year in each of the three HRDC facilities' assumed service areas was compared to the processing capacity of that facility. As might be anticipated, the highest concentration of contaminated dust would occur at the Rockwood facility, which has the smallest processing capacity. This facility's assumed service area encompasses all of NRC Region II except eastern Virginia, as well as the states of Arkansas, Louisiana and Texas. Table G-1 lists the nuclear power plants in this area, along with the amount of potentially contaminated carbon steel scrap that would be generated and the anticipated year of release. In 2024, the peak year for releases in this area, about 21,000 t of contaminated carbon steel scrap would be generated by the decomissioning of four nuclear power plants.

As discussed in Section 6.2, the amount of baghouse dust generated by the melting of the potentially contaminated steel scrap is calculated as follows:

$$M_d = \frac{M_s f_d}{f_s}$$

M_d = Mass of baghouse dust generated by the melting of contaminated steel scrap
= 333 t = 368 tons

M_s = Mass of potentially contaminated steel scrap released
= 21,121 t

f_d = mass of baghouse dust as a fraction of metal charged to furnace
= 0.015

f_s = mass of scrap imported to the facility as a fraction of metal charged to furnace
= 0.95

The dilution factor at Rockwood would therefore be approximately 0.005 (368 ÷ 75,000 ≈ 0.005).

Table G-1.
Mass of Residually Contaminated Carbon Steel Scrap Released in Rockwood HRDC Service Area

Reactor Name	Reactor Type	Power Rating (MWe)	Scaling Factor†	Mass (t)	Year* + 10	Mass Released by Year (t)+										
						2023	2024	2026	2028	2031	2032	2033	2034	2036	2037	2043
Arkansas Nuclear 1	PWR	836	0.887	2938	2024	0	2938	0	0	0	0	0	0	0	0	0
Arkansas Nuclear 2	PWR	858	0.903	2989	2028	0	0	0	2989	0	0	0	0	0	0	0
Shearon Harris 1	PWR	860	0.904	2994	2036	0	0	0	0	0	0	0	0	2994	0	0
H. B. Robinson 2	PWR	683	0.775	2568	2020	0	0	0	0	0	0	0	0	0	0	0
Catawba 1	PWR	1,129	1.084	3590	2034	0	0	0	0	0	0	0	3590	0	0	0
Catawba 2	PWR	1,129	1.084	3590	2036	0	0	0	0	0	0	0	0	3590	0	0
McGuire 1	PWR	1,129	1.084	3590	2031	0	0	0	0	3590	0	0	0	0	0	0
McGuire 2	PWR	1,129	1.084	3590	2033	0	0	0	0	0	0	3590	0	0	0	0
Oconee 1	PWR	846	0.894	2962	2043	0	0	0	0	0	0	0	0	0	0	2962
Oconee 2	PWR	846	0.894	2962	2043	0	0	0	0	0	0	0	0	0	0	2962
Oconee 3	PWR	846	0.894	2962	2044	0	0	0	0	0	0	0	0	0	0	0
Crystal River 3	PWR	820	0.876	2901	2026	0	0	2901	0	0	0	0	0	0	0	0
St. Lucie 1	PWR	839	0.89	2945	2026	0	0	2945	0	0	0	0	0	0	0	0
St. Lucie 2	PWR	839	0.89	2945	2033	0	0	0	0	0	0	2945	0	0	0	0
Turkey Point 3	PWR	666	0.763	2525	2022	0	0	0	0	0	0	0	0	0	0	0
Turkey Point 4	PWR	666	0.763	2525	2023	2525	0	0	0	0	0	0	0	0	0	0
Vogtle 1	PWR	1,105	1.069	3539	2037	0	0	0	0	0	0	0	0	0	3539	0
Vogtle 2	PWR	1,103	1.068	3535	2039	0	0	0	0	0	0	0	0	0	0	0
South Texas 1	PWR	1,250	1.16	3842	2037	0	0	0	0	0	0	0	0	0	3842	0
South Texas 2	PWR	1,250	1.16	3842	2038	0	0	0	0	0	0	0	0	0	0	0
Waterford 3	PWR	1,075	1.049	3475	2034	0	0	0	0	0	0	0	3475	0	0	0
Summer	PWR	885	0.922	3052	2032	0	0	0	0	0	3052	0	0	0	0	0
Sequoyah 1	PWR	1,122	1.08	3575	2030	0	0	0	0	0	0	0	0	0	0	0
Sequoyah 2	PWR	1,122	1.08	3575	2031	0	0	0	0	3575	0	0	0	0	0	0
Watts Bar 1	PWR	1,170	1.11	3677	2045	0	0	0	0	0	0	0	0	0	0	0
Comanche Peak 1	PWR	1,150	1.098	3634	2040	0	0	0	0	0	0	0	0	0	0	0
Comanche Peak 2	PWR	1,150	1.098	3634	2043	0	0	0	0	0	0	0	0	0	0	3634
Brunswick 1	BWR	767	0.838	5659	2026	0	0	5659	0	0	0	0	0	0	0	0
Brunswick 2	BWR	754	0.828	5595	2024	0	5595	0	0	0	0	0	0	0	0	0
Hatch 1	BWR	744	0.821	5545	2024	0	5545	0	0	0	0	0	0	0	0	0
Hatch 2	BWR	762	0.834	5634	2028	0	0	0	5634	0	0	0	0	0	0	0
River Bend 1	BWR	936	0.957	6463	2035	0	0	0	0	0	0	0	0	0	0	0
Grand Gulf 1	BWR	1,143	1.093	7384	2032	0	0	0	0	0	7384	0	0	0	0	0
Browns Ferry 1	BWR	1,065	1.043	7044	2023	7044	0	0	0	0	0	0	0	0	0	0
Browns Ferry 2	BWR	1,065	1.043	7044	2024	0	7044	0	0	0	0	0	0	0	0	0
Browns Ferry 3	BWR	1,065	1.043	7044	2026	0	0	7044	0	0	0	0	0	0	0	0
Total				145,365		9,568	21,121	18,548	8624	7165	10,436	6535	7065	6584	7381	9558

* Year of shutdown + 10 (see Table A1-1)

† See Section A.5.2.1

\+ Tabulation is for years during which two or more reactors are scheduled for decommissioning

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